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Resolving the Mystery of Transport Within Internal Transport Barriers[1]

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The Trapped Gyro-Landau Fluid (TGLF) quasilinear model, which is calibrated to approximate non-linear gyro-kinetic turbulence simulations, is now able to predict the electron density, electron and ion temperatures and ion toroidal rotation simultaneously for internal transport barrier (ITB) discharges in excellent agreement with data from the DIII-D tokamak. This is a strong validation of gyro-kinetic theory of ITBs, requiring multiple instabilities responsible for transport in different channels at different scales. Inside the ITB, the ion energy transport is observed to be reduced to the neoclassical level which is consistent with the theory of turbulence suppression by $E \times B$ velocity shear acting on low wavenumber turbulence. The electron energy transport is observed to be far above the neoclassical level which is consistent with electron energy transport due to high wavenumber electron temperature gradient (ETG) modes. Since the ETG modes do not produce particle and ion momentum transport, and low wavenumber modes are suppressed, these channels are expected to be reduced to the neoclassical level in striking disagreement with experimental measurements. A possible resolution of this conundrum was found in 2005 when gyro-kinetic turbulence simulations showed that the parallel velocity shear driven Kelvin-Helmholtz (KH) mode can arrest the suppression of transport by the shear in the $E \times B$ velocity Doppler shift at high toroidal flow shear. The success of TGLF in predicting ITB transport is due to the inclusion of ion gyro-radius scale modes that become dominant at high $E \times B$ shear and to recent improvements to TGLF that allow the KH mode to be faithfully modeled. The resolution of this long-standing mystery of the missing particle and momentum transport in an ITB is the result of the steady advances in gyro-kinetic simulations and quasilinear modeling.

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